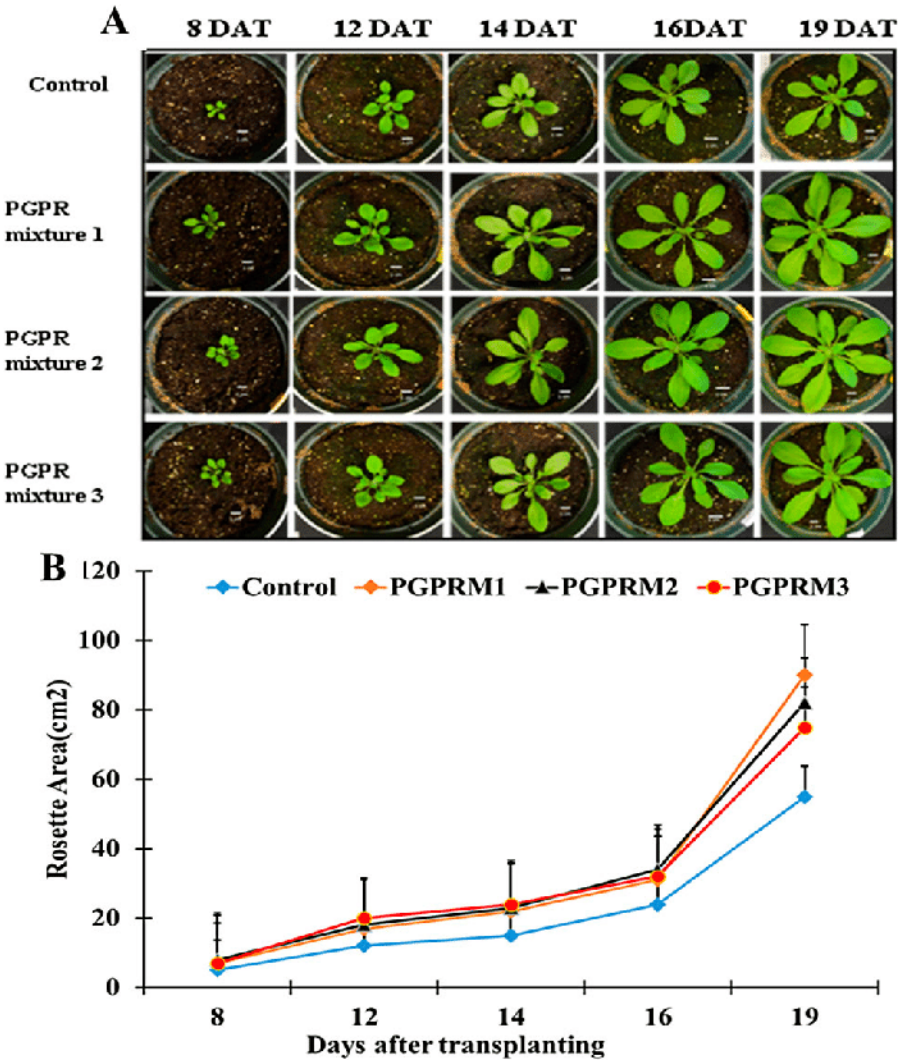
Plant Growth Promoting Rhizobacteria (PGPR) in hydroponics

Plants did not evolve in an isolated environment but with a wide variety of different microbes. Through their evolution, plants prospered more in the presence of certain microbes and therefore evolved traits to attract and nurture them. In turn these microbes were also selected to create even deeper mutualistic relationships with plants. Specifically, the bacteria from this group that facilitate and improve plant growth are known as Plant Growth Promoting Rhizobacteria (PGPR) and have been an extensive subject of plant research during the past 40 years. In this article I am going to talk about their use in hydroponic culture and the evidence we have about their growth promoting effects in the absence of soil.



Effect of PGPR of the genus Bacillus in soil, taken from this paper

The positive effects of PGPR in general are well established. These two (1, 2) literature reviews address the subject in depth and cite a lot of the research that has been done around PGPR for crops in general, although none of these two reviews address their use in hydroponics specifically. What we know from all these literature is that the positive effects of PGPR are mostly attributed to three different phenomena. The first is an increase in nutrient availability for the plant, mainly through making some nutrients that are inaccessible to the plant accessible (mostly N and P), the second is through the release of phytohormones – chemical substances that stimulate plant responses – that prompt plants to develop more tissue in several different ways, and the third is that these bacterial colonies provide defenses against pathogens that could be attacking the plant if they were not present. Many different

species that show these effects have been identified – some even specific to single plant species – but from those species those from the genus Bacillus, Agrobacterium and Pseudomonas have been the most widely studied and shown to be effective.

We also know from the research that the application of PGPR is not trivial and exactly how plants are inoculated with them plays an important role in the improvements they might show. Inoculation can be done in seeds, cuttings, transplants or through the entire growing/flowering periods. You can use both root and/or foliar applications, different concentrations of bacteria and different additives can also be given to try to make the inoculation steps more successful. These bacteria can also use oxygen in solutions, so using too much can also starve roots of important oxygen and cause strong negative effects before any positive effects can be seen, using too little means the bacteria die without being able to form a stable colony. The table below gives you an idea about how complex the entire application universe can be and the sort of effects that have been observed in field/greenhouse trials in soil for a wide variety of plants. *The reviews cited above contain a lot of additional references, make sure to read them if you're interested in a wider view of the available literature on the subject.*

Table 2
Effects of plant growth-promoting rhizobacteria (PGPR) application on fruit crops.

Crop	PGPR (species/strain)	Application mode	Experimental conditions	Effects	References
Apple	*Bacillus* sp. strain M3[a] and OSU-142[a], *Microbacterium* sp. strain FS01[e], *Pseudomonas* sp. strain BA-8[d] (alone or in combinations)	Root-dipping (10^9 CFU mL^{-1})	Field	Increased cumulative yield, fruit weight, shoot length, and shoot diameter in apple cv. Granny Smith and Stark Spur Golden	Karlidag et al. (2007); Aslantas et al. (2007)
	Bacillus sp.[a]	Foliar application of spores (10^7 spores g^{-1})	Field	Enhanced growth of apple leaves and improved fruit quality parameters (sweetness and moisture content)	Ryu et al. (2011)
Apricot	*Bacillus* sp. strain OSU-142[a]	Foliar application (10^9 CFU mL^{-1})	Field	Increased yield, shoot development and reduced shot-hole disease severity and incidence	Esitken et al. (2002, 2003)
Banana	*Pseudomonas fluorescens* strain CHA0[d]	Soil application of cells (2.5-3 10^{10} CFU) with or without chitin (treatment repeated three times)	Field	Increased growth, leaf nutrient contents and yield of banana plants under perennial cropping systems	Kavino et al. (2010)
Cherry	*Pseudomonas* sp. strain BA-8[d] and *Bacillus* sp. strain OSU-142[a] (alone or combinations)	Foliar application (spray; 10^9 CFU mL^{-1})	Field	Stimulated plant growth, increased yield per trunk, fruit weight and shoot length and resulted in significant yield increase	Esitken et al. (2006)
Grape	*Pseudomonas putida* strain BA-8[d] and *Bacillus simplex* strain T7[a] (alone or combinations)	Grafted plant-dipping (10^9 CFU mL^{-1}) for 60 min	Experimental glasshouse	Increased graft callusing, scion shoot growth, cane hardening, and nursery survival rate, as well as fruitfulness of the grapes in following year	Sabir (2013)
Hazelnut	N_2-fixing and P-solubilizing bacteria	Seed-dipping (10^9 CFU mL^{-1}), on one-year old seedlings	Pots, greenhouse conditions	Increased seedling and total branch length, branch number, trunk diameter, and nutrient uptake	Erturk et al. (2011)
Kiwifruit	*Bacillus* sp.[a], *Paenibacillus polymyxa*[a] and *Comamonas acidovorans*[c]	Seed-dipping (10^9 CFU mL^{-1}) for 30 min	Greenhouse conditions	Stimulation of rooting and root growth	Erturk et al. (2010)
Strawberry	*Bacillus subtilis* strain GBO3[a] and *Bacillus amyloliquefaciens* strain IN937a[a]	Seed-dipping with a formulation that contains both strains in a 2.5% chitin carrier	Field	Addition of PGPR to plug transplants resulted in healthier roots, earlier and higher total yields	Kokalis-Burelle (2003)
	Bacillus sp. FS-3[a]	Root drench (3.5×10^7 cell g^{-1}), repeated five times within 7-D intervals	Pots, greenhouse conditions	Increased fruit and leaf nutrient concentrations (N, P, K, Ca, and Fe)	Güneş et al. (2009)
	Azospirillum brasilense strain REC3[b], RLC1[b], PEC5[b]	Root-dipping (10^6 CFU mL^{-1}) for 30 min	Pots, greenhouse conditions	Increased root length, root area, and dry weight of root and shoot	Pedraza et al. (2010)
	Pseudomonas sp. strain BA-8[d] and *Bacillus* sp. strain OSU-142[a] and M3[a] (*alone or combinations*)	Root-dipping (10^9 CFU mL^{-1}) for 30 min or foliar application	Field	Increased fruit yield, plant growth, phosphorus and zinc content of leaves	Esitken et al. (2010)
	Bacillus spharicus GC subgroup B strain EY30[a], *Staphylococcus kloosii* strain EY37[a] and *Kocuria erythromyxa* strain EY43[e]	Root-dipping (10^8 CFU mL^{-1}) for 30 min	Pots, greenhouse conditions	Increased plant growth, fruit yield, chlorophyll content, relative water content of leaves, mineral uptake (N content of leaves and P content of roots), and reduced membrane injury under saline conditions (35 mM NaCl)	Karlidag et al. (2010)
	P. fluorescens strain Pf4[d], *Pseudomonas* sp. strain 5Vm1K[d]	Root drench with the two PRGB (5 10^9 CFU) and/or with arbuscular mycorrhizal fungi	Pots, greenhouse conditions	Increased anthocyanin concentration in fruits of plants grown under conditions of reduced fertilization	Lingua et al. (2013)
	Alcaligenes sp. strain 637Ca[c]	Root-dipping (10^8 CFU mL^{-1}) for 30 min	Pots, greenhouse conditions	Increased fruit yield, number and weight under high calcareous soil conditions	Ipek et al. (2014)
Walnut	*Pseudomonas chlororaphis*[d] *Arthrobacter pascens*5	Seed-dipping (10^9 CFU mL^{-1}), on one-year old seedlings	Greenhouse conditions	Increased plant height, shoot and root dry weight, phosphorus and nitrogen uptake	Yu et al. (2012)

Table showing the effects of different PGPR applications using different techniques across different plants. Taken from this review.

As you can see the effects under these conditions have been very positive, with sometimes highly significant increases in root/shoot weights and fruit/flower yields. However soil itself is not a perfect media and plants grown in soil are also not subjected to ideal nutrition. Since one of the main benefits of PGPR is to increase nutrient availability, some of these benefits might be partially or even completely negated when moving onto hydroponic culture, where we seek to provide

plants with an ideal environment. Research of PGPR in hydroponics is not very common though, as hydroponic growing has traditionally made a big deal about sterility, as growers mostly want to prevent pathogens from getting into their crops.

Ref	Plant	PGPR	Yield	Link
1	Tomato	Pseudomonas fluorescens, Pseudomonas putida	10%+	https://www.actahort.org/books/952/952_98.htm
2	Tomato	Pseudomonas fluorescens	13%+	https://www.sciencedirect.com/science/article/abs/pii/003807179390038D
3	Tomato	Pseudomonas putida, Serratia marcescens, Pseudomonas fluorescens, Bacillus spp	18-37%+	https://www.actahort.org/books/807/807_68.htm
4	Cucumber	Pseudomonas putida, Serratia marcescens, Bacillus spp., Pseudomonas fluorescens	78-121%	https://www.sciencedirect.com/science/article/abs/pii/S0304423813000198
5	Tomato	Bacillus amyloliquefaciens	8%	https://dialnet.unirioja.es/servlet/articulo?codigo=2740834

References of some trials using PGPR carried out in hydroponic conditions

Thankfully there have been some people who have led the way into the world of PGPR in hydroponic research so we have started to see some positive evidence of their use, even under hydroponic growing conditions. The above table shows you 5 references for papers that have studied PGPR in hydroponics – mainly in tomato plants – where it has been pretty well established that applications of bacteria of the genus Pseudomonas can increase yields in the order of at least 10%+. Some studies, like 3 and 4, show that significantly more gains are possible for different combinations of bacteria or application methods. I couldn't find a lot of additional studies in this direction, but the above studies start to show that the use of these bacteria in hydroponics can be positive.

A lot of questions still remain though. If these bacteria are benefiting plants because of the introduction of plant growth regulators (PGR) in solution, then we might ask if the direct

exogenous applications of these PGRs is not a better way to obtain and control the benefits without the need to maintain a live population of bacteria in a mutualistic relationship with plant roots. Research has indeed shown that the exogenous application of many PGRs can enhance the yields of different plants. Do we apply PGRs or do we keep a culture of bacteria in our media? Can we do both and obtain even better results? Sadly right now there are no answers to the above questions and a lot of additional research is needed before we even get close.

For now the research on PGPR is telling us that these bacteria work amazingly well in soil and can also provide substantial benefits for some plants in hydroponic culture under certain conditions. We know that the bacteria from the genus Pseudomonas and Bacillus are the most interesting candidates to study in hydroponics and we know some of the inoculation techniques that have worked. If you want to experiment with them in your hydroponic crops, make sure you take the above information into account. *The right choice of bacteria, concentration, inoculation method and additives can make a big difference in the results you get.*